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JADS JT&E

ADS Testing of C4ISR Systems

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Abstract

The End-To-End (ETE) Test, conducted under the auspices of the Department of Defense Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E), developed a synthetic test environment that can be used for future operational testing and doctrinal development. This synthetic test environment was used initially to conduct developmental and operational testing of the Joint Surveillance Target Attack Radar System (Joint STARS). As designed and built, it may be used to conduct future testing of systems such as the common ground station (CGS), the All Source Analysis System (ASAS), and the Block II Army Tactical Missile System.

This paper will describe the results of our live flight operational test utilizing satellite communications to distribute the synthetic environment and lessons learned to date. Additionally, the experience gained in verifying and validating a distributed synthetic test environment using the *Department of Defense Verification, Validation and Accreditation (VV&A) Recommended Practices Guide* will be discussed.

Background

The Joint Advanced Distributed Simulation (JADS) Joint Test and Evaluation (JT&E) was chartered by the Office of the Under Secretary of Defense (Acquisition and Technology), Deputy Director, Test, Systems Engineering and Evaluation (Test and Evaluation) "...to investigate the utility of advanced distributed simulation (ADS) for both developmental test and evaluation (DT&E) and operational test and evaluation (OT&E). JADS will investigate the present utility of ADS, including distributed interactive simulation, for T&E; and finally, identify the requirements that must be introduced in ADS systems if they are to support a more complete T&E capability in the future."

The approach taken by JADS was to select discrete, well-defined, slices of the broad T&E spectrum, conduct ADS-augmented test activities upon specific systems that are representative of these slices, and address the issues identified within our charter. In addition, ADS activity external to JADS was evaluated to provide as broad a base for our conclusions as was possible.

The emphasis of the JADS JT&E was on the performance of the ADS components and their contribution to testing, rather than any particular system under test or class of weapon system. Areas of interest included network capabilities and performance, relationships between data latencies, and ADS-induced data anomalies.

The End-To-End (ETE) Test was one of three tests within the JADS JT&E program. The JADS ETE Test was designed to evaluate the utility of ADS to support the testing of a command, control, communications, computers, intelligence, surveillance and reconnaissance (C4ISR) system, the Joint Surveillance Target Attack Radar System (STARS). Joint STARS is composed of both an airborne and ground segment along with the necessary communications subsystems. The E-8 airborne system and the ground station modules (GSM) or common ground stations (CGS) together provide the surveillance, target detection, and tracking required to assist commanders in understanding the enemy situation and taking action to destroy enemy

forces. The test design placed Joint STARS and the appropriate Army targeting and attack systems in the end-to-end loop of detect, track, target, cue a weapons system, and assess battle damage.

End-To-End Test Overview

A previous shortfall in the testing of C4ISR systems, especially those using large area sensor systems such as Joint STARS, was the inadequate numbers of forces, either friendly or adversary, available to realistically portray the expected operational environment. In addition, systems were often tested in isolation without the complementary suite of other command, control, communications, computers and intelligence (C4I) and weapon systems with which to interact. The original *Joint Surveillance Target Attack Radar System (Joint STARS) Multiservice Operational Test and Evaluation (MOT&E) Plan*, dated 21 February 1995, identified the ability to test the requirement for Joint STARS to provide support to a notional corps area of interest as a limitation of the test. As stated in the plan, the testing of this requirement "would require both a completely equipped corps operation/exercise and multiple E-8 aircraft."

Obviously, the requirement for a completely equipped corps operation/exercise was impossible to meet in 1995 and is even more impossible now. Plus, even if the testers could find a fully deployed corps involved in an operational mission, as was roughly the case in Bosnia, there would still be difficulties in testing how well Joint STARS supported the execution of attacks against detected targets.

This test limitation was the major basis for the development of the JADS ETE Test. The JADS ETE Test was designed to add an augmented operational environment, approximating a notional corps area of interest, and a complementary suite of C4ISR and weapons systems with which Joint STARS would interact.

The ETE Test used distributed interactive simulation (DIS) to assemble a synthetic environment to evaluate the utility of ADS to support the testing of Joint STARS. The intent was to provide a complete, robust set of interfaces from sensor to weapon system, including the additional intermediate nodes that would be found in a tactical engagement.

The test concept was to use ADS to supplement the operational environment experienced by the E-8C and light ground station module (LGSM) operators by adding additional entities to the battlefield seen by Joint STARS. Also, by adding additional elements of the C4I systems that Joint STARS interacts with and a weapon system, the Army Tactical Missile System (ATACMS), to engage targets, the test team could evaluate the complete battlefield environment from target detection to target assignment and engagement. It also allowed the tester to evaluate the entire thread, or the individual contribution of any of the parts, and to evaluate what effects an operationally realistic environment had on the system under test.

This was accomplished by adding approximately ten thousand simulated targets to the live targets seen by the radar on board the E-8C aircraft. This presented a battle array approximating the major systems present in the notional corps area of interest to the surveillance operators both in the air and on the ground. The nodes representing the appropriate Army C4I systems and the ATACMS were then added to provide a more robust cross section of players for interaction with the E-8C and LGSM radar surveillance operators.

Several components were required to create the ADS-enhanced operational environment used in the ETE Test. In addition to Joint STARS, the ETE Test required a simulation capable of generating thousands of entities representing the rear elements of a threat force. For this purpose, the ETE Test team selected the U.S. Army's Janus simulation.

Also, a simulation of the Joint STARS radar, called the Virtual Surveillance Target Attack Radar System (VSTARS), that simulated both moving target indicator (MTI) radar and synthetic aperture radar (SAR),

was developed to insert the simulated targets into the radar stream within the laboratory or on board the E-8C while it was flying a live mission.

The ETE Test consisted of four phases. Phase 1 developed or modified the components that allowed the mix of live and simulated targets at an E-8C operator's console and LGSM operator's console. Phase 2 evaluated the utility of ADS to support DT&E and early OT&E of a C4ISR system in a laboratory environment. Phase 3 moved components of VSTARS onto the E-8C aircraft, ensured that the components functioned properly, and checked that the synthetic environment properly interacted with the aircraft and the actual LGSM. Phase 4 evaluated the ability to perform test and evaluation in a synthetically enhanced operational environment using typical operators.

ETE Test Synthetic Environment – Phase 2 Laboratory Version

In addition to the questions regarding the utility of ADS to support DT&E and OT&E, JADS was also asked to determine if ADS had utility in improving early operational assessment of major weapon systems. Phase 2 of the ETE Test was designed to determine if an ADS-enhanced test environment could be used for developmental testing and early operational assessment of major weapon systems.

During Phase 2, the E-8C aircraft was represented by a laboratory-based simulation (VSTARS) developed by Northrop Grumman and Lockheed Martin. VSTARS is composed of the radar software used on board the aircraft and several simulations representing aircraft subsystems. VSTARS also contains two simulations representing the primary radar modes available from the E-8C aircraft.

Northrop Grumman developed the MTI radar mode simulation, called MTI SIM, by using early engineering models of the radar. The engineering models were used to develop performance curves for the radar. These performance data were then used to solve the radar equations for a given target detection. Included within MTI SIM was the capability to adjust certain radar parameters so that the simulated radar could be tuned to match actual radar performance.

Lockheed Martin (formerly Loral Defense System-Arizona) developed the SAR simulation, called the Advanced Radar Imaging Emulation System (ARIES), based upon SAR simulations developed for the Air Force's Wright Laboratory. ARIES was developed to meet Joint STARS specifications and its fidelity was tuned to meet current performance fidelity on board the aircraft. Northrop Grumman integrated it into VSTARS and it provides near real-time SAR images of anywhere within the radar area of interest.

VSTARS provides the tester the ability to conduct DT&E of Joint STARS subsystems other than the radar. Its outputs are the standard radar reports used within Joint STARS, and VSTARS must run with Joint STARS software normally used on the aircraft. During Phase 2, Northrop Grumman investigated the possible use of VSTARS to evaluate automatic tracker software contained within the next software build to be released for Joint STARS. The results of this investigation will be discussed later in this paper.

The development of VSTARS also provides the tester the ability to evaluate operational issues in a laboratory environment. Even though Joint STARS is a fielded system, it is a scarce resource that has been heavily tasked since before its fielding. The lack of available mission aircraft and the heavy workload placed on the test aircraft have made the OT&E of systems associated with the E-8C extremely difficult. Even the Army's CGS, which is a subsystem of Joint STARS, received only a limited number of sorties for operational testing.

During Phase 2, the JADS ETE Test developed the previously described synthetic environment that could be used to support early operational assessment of systems, to include Joint STARS, and could also be used to support OT&E of Joint STARS and systems that rely upon Joint STARS for targeting information. Since JADS purpose, as stated earlier, was to investigate the utility of ADS for OT&E and not to test Joint STARS, only one small slice of the operational environment was investigated. The results of our attempt to use VSTARS for early operational assessment and OT&E will also be discussed later in this paper.

ETE Test Synthetic Environment – Phase 4 Live Test Version

One of the mandated requirements for the operational testing of C4ISR systems, such as Joint STARS, is that the actual system will participate in the test. It is not, nor has it ever been, the intention of JADS to replace live testing with ADS. Rather, our intent has been to supplement, or enhance, the live testing with an ADS-enhanced test environment that more closely represents the actual operational environment the system will experience when operationally deployed.

The Phase 4 synthetic environment consisted of the same synthetic environment as was used during Phase 2 with the exception that an ADS-enhanced E-8C was used. The radar simulations used in VSTARS were moved to the aircraft and operated concurrently with the onboard radar. The data on the 10,000 virtual targets were sent to the aircraft using satellite communications (SATCOM). This enabled the aircraft, while flying over Fort Hood, Texas, to observe live, mixed and virtual MTI radar. The operators could also observe virtual and real SARS. These radar reports were then transmitted to the ground and received by an actual light ground station module and common ground station. The sensor-shooter-sensor loop was then followed with the results of the ATACMS missile strikes being observed (survivors displacing and hulks remaining) by the surveillance operators and intelligence analysts.

The operational testing conducted during Phase 4 consisted of three live trials using an ADS-enhanced test environment and five laboratory trials using the Phase 2 synthetic environment. All trials were more than five hours in duration with the exception of the last live trial which was curtailed because of the nonavailability of tanker aircraft. The lab trials filled in the test scenarios that we were not able to execute because of the lack of live trials and repeated, for comparison purposes, the scenarios executed during the live trials. Subsequent comparison of the live trials and the lab trials revealed no difference in the surveillance operators and intelligence analysts actions with regard to the virtual targets. During the second live trial, instrumented vehicles and radar reflectors were placed at Fort Hood, and JADS verified that the actual radar's performance was not affected by the ADS-enhanced test environment. The results of the Phase 4 operational test will be discussed later in this paper.

Detailed information on the ETE Test is available in an interim report for each phase and can be found at <http://www.jads.abq.com>. (After 1 March 2000, refer requests to HQ AFOTEC/HO, 8500 Gibson Blvd. SE, Kirtland Air Force Base, New Mexico 87117-5558 or SAIC Technical Library, 2001 North Beauregard St. Suite 80, Alexandria, Virginia 22311.)

Verification and Validation of the Synthetic Environment

Both the Phase 2 laboratory version and the Phase 4 live test version of the synthetic environment, including all elements of the environments, were verified, validated and accredited. The details are too extensive to cover in this paper, however they are available at the previously mentioned Web site. Two issues are worth mentioning and will be discussed as a part of this paper.

Early in the development of the ETE Test, the issue of how to validate VSTARS was brought up. Validation is the determination of "...the degree to which a model or simulation is an accurate representation of the real world from the perspective of the intended uses of the model or simulation." (DoD 5000.59-M) VSTARS needed to represent the actual radar found in the Joint STARS system closely enough so that all the operator's actions would be identical to those used for the actual system.

The ETE Test verification and validation (V&V) team decided to use a validation procedure called a Turing test, modified to meet our particular needs. A Turing test is based upon experts' knowledge about the system of interest. The experts are normally presented with two sets of output data, one obtained from the simulation and one from the system, and are asked to differentiate between the two. If they succeed, they are asked to describe the differences.

All the experts knew that it was not possible to do what we were doing without using simulation. Therefore, we presented them with output data from the simulation and asked them to differentiate between the simulation and the system based upon their experience with the system. The experts were given unlimited freedom to query and interact with the system for two hours. They were provided no instruction on the simulation except that they were to treat it as if it was a Joint STARS.

The U.S. Army Training and Doctrine Command Analysis Center (TRAC), White Sands Missile Range (WSMR), New Mexico, training directorate, conducted the modified Turing test. Individuals with Joint STARS experience performed a two-hour mission using VSTARS and then were asked to compare VSTARS with Joint STARS. The test was conducted at the Northrop Grumman facilities in Melbourne, Florida. Twelve individuals served as participants in the test. Study participants represented the Joint STARS development, testing, training, and operations communities and included Air Force, Army, and civilian personnel. Personnel acting as operators worked at the advanced tactical work stations (ATWS) in the Northrop Grumman Operations and Control Test Laboratory. The system management officer (SMO) operated from a workstation located in the Northrop Grumman JADS Laboratory.

During a pretest planning session, personnel from the Joint STARS Joint Test Force briefed participants regarding the test objective, mission scenario, and mission objectives. The mission scenario and mission objectives were available to provide structure to the test if the expert desired to use them. At the completion of each test session, a TRAC-WSMR analyst interviewed the two operators and the SMO as a group. The interview questions addressed a number of issues, including how well VSTARS simulated Joint STARS in the moving target indicator and synthetic aperture radar modes, and whether the operators were able to perform their assigned mission. The TRAC-WSMR analyst also observed the operators during the test sessions and recorded operator comments pertaining to the simulation.

All the participants thought VSTARS did a very good job of simulating Joint STARS in the MTI and SAR modes. In addition, the operators experienced no difficulties in performing their mission on the ATWS. In support of this statement, operators noted that all functions worked like Joint STARS, the windows were identical to Joint STARS, and the response rate was the same as that of Joint STARS. The participants were very impressed with the ability of VSTARS to integrate the operational scenarios into the radar products.

This ability to link the operational scenario, representing an Iraqi Army rear area, with the radar products was also commented on throughout the test. Veterans of actual Joint STARS deployments stated that it was extremely realistic. One of the common complaints voiced by surveillance operators and intelligence analysts was that there was too much operationally significant data to easily handle and process during the mission.

The full report on the modified Turing test is contained within the ETE Test V&V reports available on the JADS Web site.

The second issue was that we were unable to completely verify and validate the Phase 4 synthetic environment until the actual test trials. This was because the test synthetic environment did not exist until the aircraft was orbiting over Fort Hood.

Extensive V&V was conducted using the test aircraft on the ground, and there was a high degree of confidence that all would work during the flight. However, the radar could not be used on the ground and there were major differences in the SATCOM link, such as antenna orientation during turns, that could only be investigated during an actual flight.

During the flights, data were collected on the SATCOM performance, and the actual radar's performance was measured. Many of the V&V steps for VSTARS and the synthetic environment were repeated to ensure both were performing as expected under the actual test conditions.

End-To-End Test Results and Lessons Learned

The ETE Test had the following objectives:

JADS Issue 1. What is the present utility of ADS, including DIS, for T&E?

JADS Objective 1-1. Assess the validity of data from tests utilizing ADS, including DIS, during test execution.

JADS Objective 1-2. Assess the benefits of using ADS, including DIS, in T&E.

JADS Issue 2. What are the critical constraints, concerns, and methodologies when using ADS for T&E?

JADS Objective 2-1. Assess the critical constraints and concerns in ADS performance for T&E.

JADS Objective 2-2. Assess the critical constraints and concerns in ADS support systems for T&E.

JADS Objective 2-3. Develop and assess methodologies associated with ADS for T&E.

The results of the ETE Test are discussed in great detail in the interim reports on the four phases and in less detail in *The Utility of ADS for C4ISR System Testing* report, which can be found on www.jads.abq.com. For the purpose of this paper, we will consider the results as they apply to OT&E, to include early operational assessment, and to DT&E.

OT&E and Early Operational Assessment

The ETE Test determined that valid system under test (SUT) data could be collected on a complex C4ISR system, such as Joint STARS, both in a laboratory-based ADS test environment and in a live ADS-enhanced test environment. The Phase 2 ADS configuration could evaluate 15 out of 45 effectiveness measures of performance (MOP) (including two MOPs not evaluated during the Joint STARS contingency operations test and evaluation) and all eight effectiveness measures of effectiveness (MOE). Further, the Phase 2 ADS configuration could be used to evaluate 8 out of 27 GSM suitability MOPs.

The Phase 4 ADS configuration evaluated the same measures as the Phase 2 ADS configuration using the actual components of the system. However, if additional elements (simulated or real) were added to the Phase 4 ADS configuration, it could evaluate all 45 effectiveness MOPs (including two MOPs not evaluated during the contingency operations) and all 8 effectiveness MOEs. Furthermore, the augmented Phase 4 ADS configuration could be used to evaluate the GSM and E-8C suitability MOPs (27 out of 27 suitability MOPs), all of the human factors MOPs, and all of the software MOPs.

ADS can provide a useful tool for the tester in support of early operational testing. A laboratory version of the SUT that performs to specifications can be used, as was the case during the Phase 2 test, to assess early operational effectiveness. If the performance of the simulation can be adjusted, studies can be conducted to determine which performance values have the greatest impact on the operational effectiveness of the system.

DT&E

One of the software tools available to the operators on board the E-8C is an automatic tracker (A-tracker). This tool will automatically track a set of targets designated by the operator based upon radar reports and provide the operator with information about the targets. Northrop Grumman agreed to investigate whether or not VSTARS would be useful in testing the tracker in the laboratory prior to live testing. Prior to the use of VSTARS, laboratory (developmental) testing could only be done on a very limited basis because of the requirement for actual radar reports.

Live developmental testing was also limited because of limited resources and cost. In addition, when live testing was conducted, it used only a limited number of test cases because of the lack of test assets, time, and safety considerations.

The version of VSTARS used by Northrop Grumman to evaluate its DT&E utility was an early version and lacked critical instrumentation required for the evaluation. In addition, it was determined that a higher resolution simulation was required to drive the entities involved in the test. Despite the shortcomings, the experiment indicated that VSTARS was capable of supporting the DT&E of Joint STARS subsystems, such as the A-tracker, provided the instrumentation was added and a different scenario driver was used.

Several observations on the utility of ADS to support DT&E were made.

- Multiple repetitions of the same scenario can be performed without competing for scarce lab resources, test aircraft, and range resources.
- The use of ground-based simulations and hardware offers the potential for enormous cost savings, as compared to a live test with the aircraft.
- Any conceivable test case can be "flown" in the laboratory without worrying about safety or limited assets provided the appropriate scenario generator is available.
- Bad software can be quickly discarded and new software could be tried the next day against the entire suite of test cases.
- Most importantly, when a live test is flown, as it must be, the testers can be reasonably sure that they will get the maximum value from the flight and test conditions.

It must be noted that VSTARS ran on one workstation during this test as opposed to the extensive radar laboratory normally required for developmental testing of the tracker. It truly provided the ability to do desktop testing. Use of the Phase 4 test environment would also allow the tester to test against available live test cases and against normally unavailable virtual test cases, thereby maximizing the use of the test flight.

Lessons Learned

- An ADS-enhanced live test environment using validated simulations can provide more realistic threats and force levels than those offered by conventional tests, i.e., threats/levels otherwise unavailable because of cost restrictions, unobtainable threats, etc.
- C4ISR system testers can tailor the simulation entities operating in the ADS environment to closely reflect the forces expected in operational theaters, thus further increasing the relevance of the collected test data.
- ADS allows testers to have more control over the specific aspects of the scenarios of interest and to expand their test concept and design. A typical constraint to test concept development is the number and types of units readily available for a test.
- ADS technology can easily eliminate the conventional testing disadvantage of insufficient battlespace. For example, the National Training Center occupies about one thousand square miles. In contrast, the battlespace for Phase 2 of the ETE Test was almost ten times larger. In fact, ADS technology is capable of supporting even larger battlespaces.
- Using ADS, testers can conduct more test trials for longer periods of time. During the Phase 2 test, the ETE Test team was able to conduct five test trials, lasting six hours each, within a 5-day period. A maximum of three trials could have been conducted using the test aircraft. If additional shifts of operators were available, the test trails could have lasted longer at little additional cost. Because of scheduling issues, crew rest, and the lack of test aircraft, it would be difficult to extend a live test trial beyond five to six hours on station. During the Phase 4 test, the ETE Test team was able to conduct eight test trials using three live test trials and five laboratory

test trials. The laboratory test trials were mainly conducted during the periods between live test trials at little or no additional cost.

- The ETE Test also demonstrated that there are no real technical barriers to using an ADS environment to provide a realistic test environment for a C4ISR system. This is due to the high reliability of the network architecture underlying an ADS environment and the dramatic increases in computer processing and storage capabilities over the past few years. Rather, the key constraints to ADS testing are the familiar ones of time and money.
- ADS allows the tester to assemble, using models, simulations, emulators, and fielded systems, systems of systems that either have not yet been built or would not exist except in time of war. During the ETE Test, an ATACMS missile was fired at an enemy force based on operationally realistic intelligence collected by Joint STARS and processed by an element of ASAS. This was done using fielded C4ISR systems that were electronically linked and functioning as they would in combat. Army intelligence subject matter experts stated that, to the best of their knowledge, this had never been done before the ETE Test.
- ADS can easily provide models and simulations that represent the threats of today and the threats of tomorrow. All models and simulations of threats, no matter what their fidelity, are data driven. The fidelity is determined by the accuracy and detail contained within the data and the fidelity of the algorithms that use the data to depict the threat. During the ETE Test, the threats used were those currently fielded within the Iraqi Army. They could have just as easily been low observable threats from a future battlefield.

Conclusion

As stated in the JADS report, *The Utility of ADS for C4ISR System Testing*:

Since all C4ISR systems contain the same basic elements (e.g., sensor(s), sensor platform(s), command and control elements, communication lines, and computer hardware and software), the extension of the ETE Test results to other possible C4ISR applications is relatively straightforward. ADS technology allows the evaluation of human-in-the-loop actions, decision processes, timelines, and interoperability which digital simulations do not model well. Using ADS, a mission-level scenario model can be linked to actual C4ISR hardware and software with tactical operators-in-the-loop and tactical communications links for realistic testing in force-on-force scenarios which cannot be accomplished in live testing.

ADS is not just of value to C4ISR T&E but can be applied throughout the system acquisition life cycle. In fact, the benefits of using ADS are best realized over the life of a program. ADS is an enabling technology for Simulation Based Acquisition (SBA) and the Simulation, Test, and Evaluation Process (STEP) as applied to C4ISR systems, since these systems are naturally distributed by nature.

Future uses of ADS currently being discussed are a follow-on test of the CGS, the operational test for the Block 20 E-8C (computer replacement program), and operational testing of the Block II ATACMS missile. All these programs are currently investigating the use of VSTARS and elements of the ETE Test synthetic environment.

Gary J. Marchand was the technical lead for the End-to-End (ETE) Test of the Joint Advanced Distributed Simulation Joint Test Force. He was the principle designer of VSTARS and the synthetic environment used for the ETE Test. He received a bachelors degree from the United States Military Academy and an Master of Science Degree in Applied Science from the University of California at Davis. He retired from

the U.S. Army in 1993 after having been the deputy director and senior military analyst at the U.S. Army Training and Doctrine Command Analysis Command, White Sands Missile Range. He is currently employed as a senior analyst by Science Applications International Corporation (SAIC).